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Secondary Calorimetric Power Calculation Based on Main Steam Flow

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1. Introduction

A new reactor power calculation method using steam flow rate has been studied for the OPR1000 plants. In this calculation method a mathematical flow equation is developed based on steam flow rate in a similar way to feedwater flow based power calculation method. The detailed method is described herein from the steam mass flow rate equation to the representative results of this calculation.

2. Methods and Results

In this section the method used to calculate the steam flow based power is described. The steam mass flow rate model includes a correction factor which is determined on plant startup.

2.1 Steam Mass Flow Rate Equation

The mathematical form of steam mass flow rate for the steam flow based secondary calorimetric power (MSBSCAL) is similar to that of feedwater mass flow rate for the main feedwater flow based secondary calorimetric power (FWBSCAL) using ASME theory[1].

$$W = 358.93\left(\frac{Y \cdot d^2 \cdot F_a}{\sqrt{1-\beta^4}}\right)\left(2\sqrt{\rho_s \Delta P}\right)(CF) \tag{1}$$

Where

W = Mass flow rate (lbm/hr),

Y = Expansion factor,

F_a = Area thermal expansion factor [2],

d = Diameter of venturi throat (inch),

β = d/D, the ratio of venturi throat diameter to downstream pipe diameter,

ΔP = Average value of differential pressures at 68 deg F (inch),

ρ_s = Density of flowing steam with steam quality considered (lbm/ft^3),

CF = Correction factor.

The correction factor, CF, corresponds theoretically to discharge coefficient which is defined as the ratio of actual flow rate to theoretical flow rate [1, 2, 3]. This factor is determined for each plant startup.

2.2 Steam Flow Differential Pressure Determination

The OPR1000 plants have two steam nozzles for each steam generator. For our analysis, two differential pressure signals per steam generator are averaged as follows:

$$\Delta P = \frac{\Delta P_1 + \Delta P_2}{2} \tag{2}$$

Where

ΔP_1 = Measured differential pressures for nozzle 1,

ΔP_2 = Measured differential pressures for nozzle 2

This method introduces conservatism in the calculated differential pressure value according to the following inequality:

$$2\sqrt{\frac{\Delta P_1 + \Delta P_2}{2}} \geq \sqrt{\Delta P_1} + \sqrt{\Delta P_2} \tag{3}$$

The difference of 10 % between the two nozzle differential pressures gives about 0.035 % overestimation in the calculated flow rate.

2.3 Steam Pressure Determination

The steam pressure is determined to be an average of the derived steam pressure from the measured steam header pressures and the center-averaging of the measured steam pressures. This method gives the benefit of reducing related uncertainties.

$$P_{SG} = \frac{P_{CSG} + P_{MSG}}{2} \tag{4}$$

$$P_{CSG} = P_{SHP} + a + b\Delta P \tag{5}$$

$$P_{MSG} = \frac{\sum P_i - \min(P_i) - \max(P_i)}{2} \tag{6}$$

Where

P_{SG} = Determined steam pressure,

P_{CSG} = Calculated steam pressure from steam header pressures,

P_{MSG} = Center-averaging steam pressure,

a, b = Constants.

The steam header pressure used in the calculated steam pressure is an average of the two measured header pressures which are measured at the common header between the two steam generators. The differential pressure used in the calculated steam pressure is an average of the two measured steam nozzle differentials.

Inspection of the safety channel pressures showed that all four channel pressures have reasonable values. Therefore, rather than center-averaged value, the four-averaging gives the best estimate of steam generator pressure. However, in case of channel failure, it is reasonable to use center-averaging.

2.4 Steam Flow Correction Factor Determination

The steam flow DP transmitters measure the pressure drop between the steam generator dome top pressure tap and a point at the venturi throat. The pressure drop consists of unrecovered loss from the integral flow nozzles plus nozzle entrance shock loss. The pressure drop can not be predicted by design to the precision required; therefore, the steam flow transmitters or the steam flow rate can be adjusted on startup to make the steam flow calculated the same as the highly accurate feedwater flow indication. A startup procedure for this test has been developed.

In this procedure the correction factor is determined on plant startup by comparing with the feedwater mass flow rate for each steam generator. The required data are collected with the blowdown flow isolated.

The figure 1 shows the determined correction factors using cycle 10 data at the YGN 4 plant. It shows that the correction factors are a weak function of relative flow to the reference full flow. Also the correction factors are shown to be a little different for each steam generator.

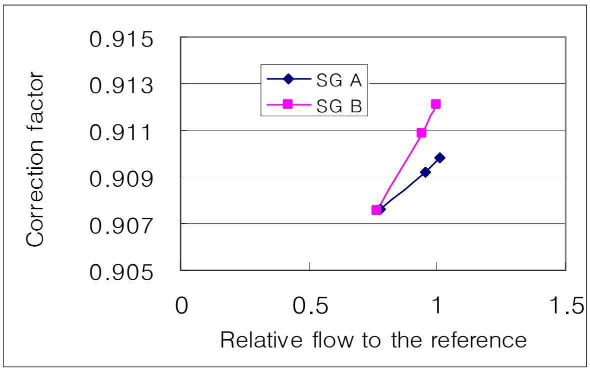

Figure 1. Estimated steam flow correction factor

3. Conclusion

A mathematical steam mass flow rate equation has been developed to be used in the reactor thermal power calculation. Also the determination methods of the basic inputs to the flow equation have been set up and finally sample correction factors have been estimated. This power calculation method is useful for application of power monitoring together with the current feedwater flow based power monitoring.

REFERENCES

[1] "APPLICATION – Part II of Fluid Meter," 6th Ed., 1971, ASME, New York, N. Y.

[2] ASME PTC 19.5-2004, Flow Measurement – Performance Test Codes.

[3] ASME MFC-3M-2004, Measurement of Fluid Flow in Pipes Using Orifice, Nozzle, and Venturi.